Surface Metrology

Program Manager: Theodore V Vorburger
Total FTE: 9.5
Total Funding: $1,317,000

Goal

To deliver to U.S. industry measurement services in surface and microform metrology of unimpeachable quality and of a variety that industry requires.

Program Objectives

FY2003

Develop phase-shifting interferometry into a traceable test service for non-contact measurement of step heights.

FY2002

Develop and apply phase-shifting interferometry for calibration of master step heights to provide a new, independent traceability path for surface metrology to the unit of length.

FY2001

Complete development of a software system for display of long-term control charts for both surface roughness and step-height measurements.

FY2000

Develop and apply high-speed gaussian filter software in surface roughness measurements to maintain compliance with international standards for surface finish analysis.

Surface Finish Metrology, Software Development

Improve the measurement systems, physical standards, and models that underpin industry's measurements of surface finish and step height and especially during fiscal year (FY) 2000 the software measurement system for surface texture calibrations.

FY2000

Demonstrate distributed fabrication and inspection of an atom-based dimensional standard using surface science techniques for the fabrication and inspection and vacuum technology for the transfers between systems.

National Advanced Manufacturing Testbed (NAMT) Nano-manufacturing of Atom-based Standards

Develop the techniques for fabrication and inspection of atom-based dimensional standards and the vacuum techniques to transport the specimens to the point that a complete transfer from a fabrication facility to an inspection facility and back again can be made without harm to the specimen.

FY2004

Complete the certification of a standard reference material having calibrated pitch features in the x- and y- directions and calibrated step heights in the z-direction for calibration of scanned probe microscopes used in nanotechnology industries.

FY2002

Make operational a calibration service of pitch or height artifacts used for calibration of scanned probe microscopes.

FY2001

Certify Standard Reference Material (SRM) 2070, the Scanning Electron Microscope (SEM) magnification standard, in cooperation with the Manufacturing Engineering Laboratory's Nano-Scale Metrology group.

FY2000

Complete acquisition of motion and sensor systems for upgrade of the Calibrated Atomic Force Microscope (C-AFM) with improved vertical noise and lateral range.

Calibrated Microscopy, Instrument Development

Provide the calibration infrastructure for high-resolution surface microscopes used in U.S. manufacturing industries by upgrading the performance of the Calibrated Atomic Force Microscope.

FY2004

Develop scanning white light interferometric microscopy into a tool for traceable measurements of part dimensions in the millimeter to micrometer scales.

FY2002

Develop a series of NIST standard grade Rockwell indenters as U.S. primary standards for Rockwell hardness measurement.

FY2001

Develop and calibrate an optical system for measurements of hardness indenters and other micromechanical components.

FY2000

Issue a report of test of the microgeometry of indenters to be used in the forthcoming international round robin of hardness measurements.

Microform Metrology, Indenter Characterization

Demonstrate a metrology approach for unifying the U.S. and international hardness measurement scales by supporting an international round robin in the field with the world's most accurate measurements of the dimensions and geometry of Rockwell C hardness indenters.

FY2000

Complete a draft report on step height measurements for ASTM Subcommittee E42.14 on Scanning Tunneling Microscopy (STM) / Atomic Force Microscopy (AFM).

Surface Metrology Standardization, Step Heights

Support industry's efforts to develop national and international documentary standards in surface metrology by developing improved procedures for step height measurements by scanned probe microscopes.

Customer Needs

The surface finish affects the function of industrial products ranging from roadways through ship hulls and propellers, motor vehicles, planes, and rockets, to microelectronics and optics. According to the "1998 U.S. Industry and Trade Outlook", the value of shipments by U.S. manufacturers in motor vehicles alone was forecast to be $227 B in 1998. For the microelectronics and aerospace industries, those figures were forecast to be $169 B and $133 B, respectively. Many functional surfaces of these products must be specified and measured for surface finish as well as for certain dimensional parameters of microscopic surface features. The functional properties affected by the surface finish include friction and wear, semiconductor integrity, optical imaging quality, and customer perception of quality based on appearance. NIST calibrations and measurement research are critical to maintaining an accurate national measurement system for surface metrology as are NIST contributions to numerous standards committees to formulate mutually agreeable and meaningful measurement results. An important part of this system is accurate calibration of critical surface features such as the radius of hardness indenters for the metals industry or step heights and pitch spacings for the semiconductor industry. NIST calibrations are needed, for example, to support measurements of a variety of parameters including average and root mean square roughness, power spectral density of roughness, hardness indenter radius and cone angle, and feature heights and spacings in the semiconductor and data storage industries.

Technical Approach

The technical approach includes: providing calibrations and services that support surface metrology and scanned probe microscopy, applying the calculation of electromagnetic wave scattering to critical surface metrology problems, supporting comprehensively industry's efforts to develop national and international documentary standards in surface metrology and scanned probe microscopy, providing standard reference materials having properties that industry cannot supply for itself, and resolving methods divergences in surface measurements between different techniques, different laboratories, and different countries.

We primarily use high resolution profiling instruments to perform calibrations of standards and tests of industrial components. These instruments include five stylus instruments, the calibrated atomic force microscope (C-AFM) and two other atomic force microscopes, and two optical interferometric microscopes. In addition we house the world's first metrology scanning electron microscope. These profiling instruments are calibrated directly with laser interferometers or indirectly with master artifacts calibrated by optical interferometry. Using new techniques we are continuously upgrading either the hardware or software of these instruments or the calibration of our master artifacts, producing new standard reference materials (SRMs), or improving the accuracy, automation, and flexibility of our instruments to meet new customer requirements.

Our collaborators include semiconductor manufacturers such as Texas Instruments, instrument vendors such as Thermo Microscopes and Veeco Instruments, vendors of specimen standards such as VLSI, Standards, Inc. One important industry collaboration is a round robin intercomparison of single atom step height specimens as potential calibration standards. Numerous industry roadmaps, such as the NTRS (National Technology Roadmap for Semiconductors) and OIDA (Optoelectronics Industry Development Association) Roadmaps influence the directions we take and ambitious goals that we set. We also collaborate closely with other National Measurement Institutes (NMI's) and foreign laboratories through Guest researcher Agreements and Bureau International des Poids et Mesures (BIPM) Key Comparisons. In the near future, our success may be measured by our performance in the upcoming Key Comparisons and the availability of traceable atom-based standards. Numerous archival publications including two prestigious review articles have resulted from this work, which was also highlighted in several trade journals during FY 1999.

2000 Additional Program Information

The team of Ronald Dixson and Joseph Fu (with collaborators Rainer Koning, Vincent Tsai, and Ellen Williams) won the 1999 Applied Research Award for Development of the Calibrated Atomic Force Microscope.

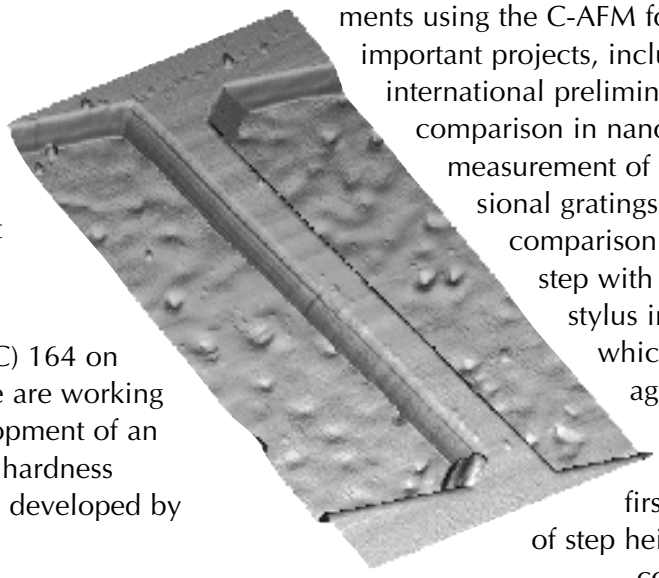
Standards Participation

- American Society of Mechanical Engineers (ASME) B46 National Standards Committee on the Classification and Designation of Surface Qualities: Member, former Chair, and former Chair of the Editorial Working Group that resulted in the publication of the 1995 revision of ASME B46.1, "Surface Texture"; presently leader of a Task Group (TG) to consider changes to the above standard.
- ASME B46 Sub-Committee (SC) 1 on Profile Methods: Member and former Chair

- ASME B46 SC6 on Nanometer Surface Texture: Member. This sub-committee developed a draft national standard for procedures and calibration of instruments performing surface texture measurements at the nanometer level and completed a ballot of the committee.
- ASME B46 SC7 on Computational Surface Texture Metrology: Member. This sub-committee completed a draft of software procedures for calculation of key surface texture parameters and is undergoing a ballot of the software compendium, proposed as an appendix to the ASME B46.1 standard.
- ASME B46 SC9 on Fractal Methods: Member. This sub-committee completed a draft and one ballot of a new appendix describing fractal methods for surface analysis.
- ASTM E42.14 on Surface Analysis STM/AFM: Participant. We recently began work to develop a draft appendix on step height measurement using scanned probe microscopes.
- ISO Technical Committee (TC) 164 on SC3 on Hardness Testing: We are working with this group on the development of an international round robin for hardness measurement using indenters developed by NIST.
- ISO TC184 on Industrial Automation Systems and Integration, SC4 on Industrial Data: Project Leader. This project involves development of a Preliminary Work Item to develop an Application Protocol (AP) 219 on Dimensional Inspection Information Exchange.
- ISO TC213 on Dimensional and Geometrical Product Specifications and Verification: Liaison Officer to ISO TC172 on Optics and Optical Instruments
- ISO TC213 Working Group (WG) 5 on Calibration Procedures for Surface Texture: Subject Matter Expert (SME). This WG developed or revised approximately five new draft international standards for surface texture measurement.
- ISO TC213 WG8 on Drawing Indication of Surface Texture: SME. The balloting of the revision of this draft standard has recently been completed.
- US Technical Advisory Group to ISO TC213: Member. This group organizes the US interaction with ISO TC213 and reviews approximately 12 new draft standards each year.

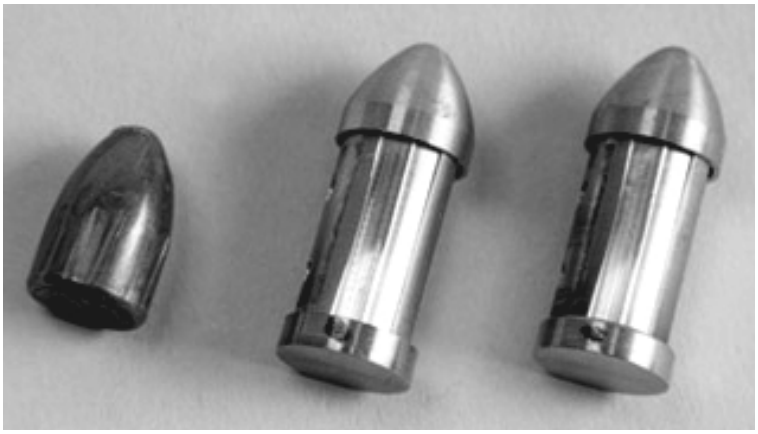
Accomplishments

- September FY1999 Completed measurements using the C-AFM for a number of important projects, including 1) an international preliminary key comparison in nanometrology for measurement of one dimensional gratings, 2) an internal comparison of a 90 nm step with a calibrated stylus instrument in which 0.28 nm agreement was obtained, 3) the C-AFM's first report of test of step heights, 4) a comparison with SEM and electrical measurements of linewidth, and 5) exploratory measurements of edge roughness and depth of the information carrying pits on data storage media.



C-AFM image of a 500 nm linewidth

- January FY1999 -Participated strongly as the US principal Subject Matter Expert in the ISO TC 213 Advisory Group 5 on Future Needs for Surface Texture Standardization. NIST viewpoint and US interests as the world's leading manufacturers of scanned probe and interferometric microscopes were promoted in AG5's draft final report.
- November FY1999 Two new mechanical designs were developed using CADKEY Solid Models and one existing design was converted into CADKEY Solid Models. The new designs are for a portable ultra-high-vacuum artifact transport system and an improved force sensor for the C-AFM. The converted design is the original design for the C-AFM. Simulations of these complex systems now can be viewed and rotated in real time to enable coworkers to understand quickly the concepts, strengths, and limitations of the mechanical designs.
- August FY1998 Developed a Memorandum of Understanding with National Aeronautics and Space Administration (NASA) to cooperate on technology and metrology development for large optics. This agreement is part of NASA's plan for development of future generations of astronomical observatories
- July FY1998 Performed first special test for a customer of the geometry of Rockwell hardness indenters; performed similar tests of hardness indenters proposed for use by an international intercomparison; received the news that one of NIST's standard indenters will be used for the international intercomparison.
- July FY1998 Completed the world's most precise step height measurement with an uncertainty (k=2) of 8 pm; Published reports of this work in Applied Physics Letters and the AIP Conference Proceedings On Characterization and Metrology for ULSI Technology; and Distributed a set of these specimens to industry for evaluation. This work is being done under NIST's National Advanced Manufacturing Testbed (NAMT) program with the goal of providing industry with atom based step height standards for use with high resolution scanned probe microscopes in the semiconductor and data storage industries. The participants include Texas Instruments, IBM, Veeco Instruments, and Topometrix.
- July FY1998 Completed the first round of measurements of linewidth using the C-AFM (Calibrated Atomic Force Microscope) as part of the linewidth correlation project in cooperation with Electronics and Electrical Engineering Laboratory (EEEL).
- July FY1998 In cooperation with the Manufacturing Engineering Laboratory's (MEL's) Automated Production Technology Division (APTD) and Fabrication Technology Division (FTD), used the NC (numerical control) diamond turning process to fabricate two types of precise surface roughness specimens: 1) random, uniaxial roughness standards with high uniformity over their surfaces and 2) highly repeatable quality control bullets for verify-



Quality control bullet (left) provided by the Bureau of Alcohol, Tobacco and Firearms as a master to fabricate two prototype NIST standard bullets (right) with identical surface profile signatures.

ing the operation of optical imaging instruments used in crime labs to link weapons to crimes. The former is important to the metalworking industry, the latter is important to law enforcement organizations all over the world.

- June FY1998 Issued first report of test for pitch measurements with the C-AFM to an industrial customer. Test service highlighted in Quality Magazine and Photonics Spectra
- June FY1998 Cooperated with MSEL to lead a Workshop on Rockwell Hardness standardization. This work is part of our program to enable the development of a world unified Rockwell Hardness scale using rigorous, Systeme Internationale d'Unites (SI)-traceable metrology.
- June FY1998 Spearheaded the establishment of a Preliminary Work Item On Dimensional Inspection Information Exchange under TC184 SC4 on Industrial Data through concerted discussion and document preparation.
- January FY1998 Completed the coordination, analysis, and publication of the results of an industrial round robin of power spectral density measurements of a set of silicon wafers. The participants included Silicon Genesis, Digital Instruments, Chapman Instruments, ADE Corp., and ADE Optical Systems.
- November FY1998 Cooperated with Guest Researcher Yibao Yuan in the development of an ingenious, high speed, accurate algorithm that performs Gaussian filtering on time-series and topography data; drafted three articles on the subject and submitted one of them to Precision Engineering. The gain in speed over the conventional Gaussian filter is approximately 70-fold.
- October FY1998 Reduced the uncertainty of the C-AFM (Calibrated Atomic Force Microscope) for step height measurements to 0.2 nm (k=2) and performed a successful comparison with a step height supplied and calibrated by PTB (Physikalisch-Technische Bundesanstalt) in Germany.
- October FY1998 Computed the scattering of light by simulated overlay targets using a rigorous electromagnetic theory and conveyed these results for input into a microscope imaging simulation.

FY2000 Measurement Services

Calibrations

- 15010C Roughness Calibration Specimens

  Provides traceable roughness measurements to the metalworking and other discrete parts industries as part of a component of NIST's dissemination

- 15040S Special Roughness Tests

  Provides traceable measurements of a range of roughness and surface topography parameters such as the dimensional and geometrical properties of hardness indenters or the pitch or step height of dimensional standards for scanned probe microscopes.

- 15020C Surface Roughness Comparison Specimens

  Provides traceable measurements of real world roughness specimens to the automotive, aircraft, and other metalworking industries.

- 15030C Step Height Calibrations

  Provides dissemination of the unit of length to industries requiring high resolution profiling of surfaces, including automotive, aircraft, optics, microlectronics, and data storage.

SRM

- Particle Diameter Standards SRMs 1690, 1691, 1692, 1960, 1961, 1965

  These particle diameter standards cover the range of diameters from 300 nm to 30 um. One of them is a glass microscope slide having arrays of 10 um particles made in space for use with optical microscopes

- SRM 484 and 2070 SEM Magnification Standards

  This popular standard, which has been restocked and sold out seven times, serves as the dissemination of the unit of length for scanning electron microscopes, principally in the microelectronics and related industries.

- Sinisoidal roughness blocks, SRMs 2071, 2072, 2073, 2074, 2075

  This series of precision roughness standards includes certified values for both roughness height and spatial wavelength and is a component of NIST's dissemination of the unit of length primarily to the discrete parts industries.